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अनुभाग 40 एटेनुएशन

Indian Standard

OPTICAL FIBRES

PART 1 MEASUREMENT METHODS AND TEST PROCEDURES

Section 40 Attenuation

ICS 33.180.10

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Fibre Optics, Fibres, Cables and Devices Sectional Committee, LITD 11

NATIONAL FOREWORD

This Indian Standard (Part 1/Sec 40) which is identical with IEC 60793-1-40 : 2001 'Optical fibres — Part 1-40: Measurement methods and test procedures — Attenuation' issued by the International Electrotechnical Commission (IEC) was adopted by the Bureau of Indian Standards on the recommendation of the Fibre Optics, Fibres, Cables and Devices Sectional Committee and approval of the Electronics and Information Technology Division Council.

The text of IEC Standard has been approved as suitable for publication as an Indian Standard without deviations. Certain conventions are, however, not identical to those used in Indian Standards. Attention is particularly drawn to the following:

a) Wherever the words 'International Standard' appear referring to this standard, they should be read as 'Indian Standard'.

b) Comma (,) has been used as a decimal marker while in Indian Standards, the current practice is to use a point (.) as the decimal marker.

In this adopted standard, reference appears to certain International Standards for which Indian Standards also exist. The corresponding Indian Standards which are to be substituted in their respective places are listed below along with their degree of equivalence for the editions indicated:

International Standard	*Corresponding Indian Standard*	*Degree of Equivalence*
IEC 60793-1-22 : 2001 Optical fibres — Part 1-22: Measurement methods and test procedures — Length measurement	IS/IEC 60793-1-22 : 2001 Optical fibres: Part 1 Measurement methods and test procedures, Section 22 Length measurement	Identical
IEC 60793-1-43 : 2001 Optical fibres — Part 1-43: Measurement methods and test procedures — Numerical aperture	IS/IEC 60793-1-43 : 2001 Optical fibres: Part 1 Measurement methods and test procedures, Section 43 Numerical aperture	do

Only the English language text has been retained while adopting it in this Indian Standard and as such the page numbers given here are not the same as in the IEC Publication.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

Indian Standard

OPTICAL FIBRES

PART 1 MEASUREMENT METHODS AND TEST PROCEDURES

Section 40 Attenuation

1 Scope

This part of IEC 60793 establishes uniform requirements for measuring the attenuation of optical fibre, thereby assisting in the inspection of fibres and cables for commercial purposes.

Four methods are described for measuring attenuation, one of which being that for modelling spectral attenuation:

- method A: cut-back;
- method B: insertion loss;
- method C: backscattering;
- method D: modelling spectral attenuation.

Methods A to C apply to the measurement of attenuation for all categories of the following fibres:

- class A multimode fibres;
- class B single-mode fibres.

Method C, backscattering, also covers the location, losses and characterization of point discontinuities.

To date, method D has been demonstrated only on class B fibres.

Information common to all three measurements, and to the modelling method, appears in clauses 1 to 8, and information pertaining to each individual method appears in annexes A, B, C, and D, respectively.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of IEC 60793. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of IEC 60793 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of IEC and ISO maintain registers of currently valid International Standards.

IEC 60793-1-22, *Optical fibres – Part 1-22: Measurement methods and test procedures – Length*

IEC 60793-1-43, *Optical fibres – Part 1-43: Measurement methods and test procedures – Numerical aperture*

3 Definitions

For the purpose of this part of IEC 60793, the following definitions apply.

NOTE Attenuation is a measure of the decreasing optical power in a fibre at a given wavelength. It depends on the nature and length of the fibre and is also affected by measurement conditions.

Uncontrolled launching conditions normally excite higher order lossy modes that produce transient losses and result in attenuation that is not proportional to the length of the fibre. A controlled, steady-state launching condition yields attenuation that is proportional to the fibre's length. Under steady-state conditions, an attenuation coefficient of a fibre can be determined and the attenuation of concatenated fibres added linearly.

3.1
attenuation

attenuation of a fibre at wavelength λ between two cross-sections, 1 and 2, separated by a distance and defined as

$$A(\lambda) = \left| 10 \log_{10} \frac{P_1(\lambda)}{P_2(\lambda)} \right| \tag{1}$$

where

$A(\lambda)$ is the attenuation, in dB, at wavelength λ;

$P_1(\lambda)$ is the optical power traversing cross-section 1;

$P_2(\lambda)$ is the optical power traversing cross-section 2.

3.2
attenuation coefficient
attenuation per unit length

for a uniform fibre under steady state conditions, it is possible to define the attenuation per unit length or the attenuation coefficient as follows:

$$\alpha(\lambda) = \frac{A(\lambda)}{L} \tag{2}$$

which is independent of the chosen length of the fibre;

where

$\alpha(\lambda)$ is the attenuation coefficient;

$A(\lambda)$ is the attenuation at wavelength λ;

L is the length, in kilometres.

3.3
spectral attenuation modelling

technique that predicts the attenuation coefficients across a spectrum of wavelengths from a small number (three to five) of discrete values measured directly

3.4
point discontinuities

temporary or permanent local deviation of the continuous OTDR signal in the upward or downward direction

NOTE The nature of the deviation can vary with test conditions (e.g. pulse duration, wavelength, and direction of the OTDR signal). Although a point discontinuity can have a length greater than the corresponding displayed pulse duration (including transmitter and receiver effects), the length is usually about equal to the pulse duration. For a correct interpretation, the guidelines in IEC 60793-1-22 should be followed for measuring length.

4 Calibration requirements

Under consideration.

5 Reference test method

Method A, cut-back, is the reference test method (RTM), which shall be the one used to settle disputes.

6 Apparatus

Annexes A, B, C, and D include layout drawings and other equipment requirements for each of the methods, respectively.

7 Sampling and specimens

7.1 Specimen length

The specimen shall be a known length of fibre on a reel, or within a cable, as specified in the detail specification.

7.2 Specimen end face

Prepare a flat end face, orthogonal to the fibre axis, at the input and output ends of each specimen.

8 Procedure

See annexes A, B, C and D for methods A, B, C and D, respectively.

9 Calculations

9.1 Methods A and B

Methods A and B, cut-back and insertion loss, respectively, use equations (1) and (2), which appear in 3.1 and 3.2.

9.2 Method C

See annex C.

9.3 Method D

See annex D.

10 Results

10.1 Information available with each measurement

Report the following information with each measurement:

- date and title of measurement;
- identification of specimen;
- optical source wavelength;
- specimen length;
- spectral attenuation, dB, or attenuation coefficient, dB/km, versus wavelength or at specific wavelength(s), as required by the detail specification.

10.2 Information available upon request

The following information shall be available upon request:

- measurement method used: A, B, C, or D;
- type of optical source used: central wavelength(s) and spectral width(s);
- launching technique and conditions used;
- indication if a dead-zone fibre was used;
- description of all key equipment;
- for type B fibres – dimensions and number of turns of the mode filter or mode scrambler;
- pulse duration(s), scale range(s), and signal-averaging details;
- details of computation technique (calculation method);
- any deviations to the procedure that were made;
- date of latest calibration of measurement equipment.

For methods C and D, see the additional requirements in C.5 of annex C and in D.5 of annex D, respectively. This particularly applies when using method C for measuring point discontinuities.

11 Specification information

The detail specification shall specify the following information:

- type of fibre (or cable) to be measured;
- failure or acceptance criteria at the wavelength or wavelength range;
- any deviations to the procedure that apply;
- information to be reported.

Annex A
(normative)

Requirements specific to method A – Cut-back

The cut-back technique is the only method directly derived from the definition of fibre attenuation, in which the power levels, $P_1(\lambda)$ and $P_2(\lambda)$, are measured at two points of the fibre without change of input conditions. $P_2(\lambda)$ is the power emerging from the end of the fibre, and $P_1(\lambda)$ is the power emerging from a point near the input after cutting the fibre. (This explains its wide acceptance as the reference test method for attenuation.)

This measurement principle does not permit information on the attenuation behaviour over the length of the fibre. Neither is it easy to measure the change of attenuation under changing conditions. In some situations, its destructive nature is a disadvantage.

A.1 Apparatus

A.1.1 General apparatus for all fibres

See figures A.1 and A.2 for diagrams of suitable test set-ups.

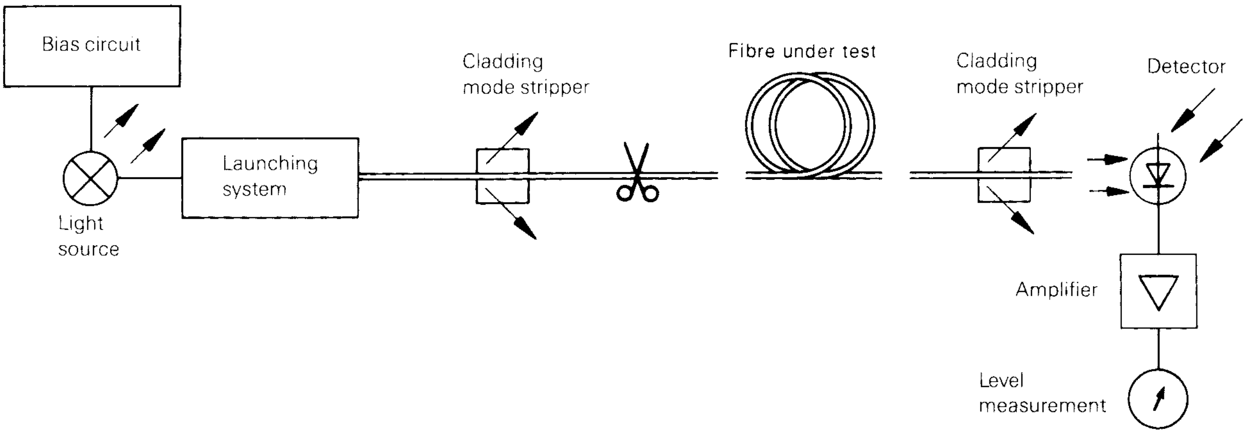

Figure A.1 – Arrangement of equipment to make loss measurement at one specified wavelength

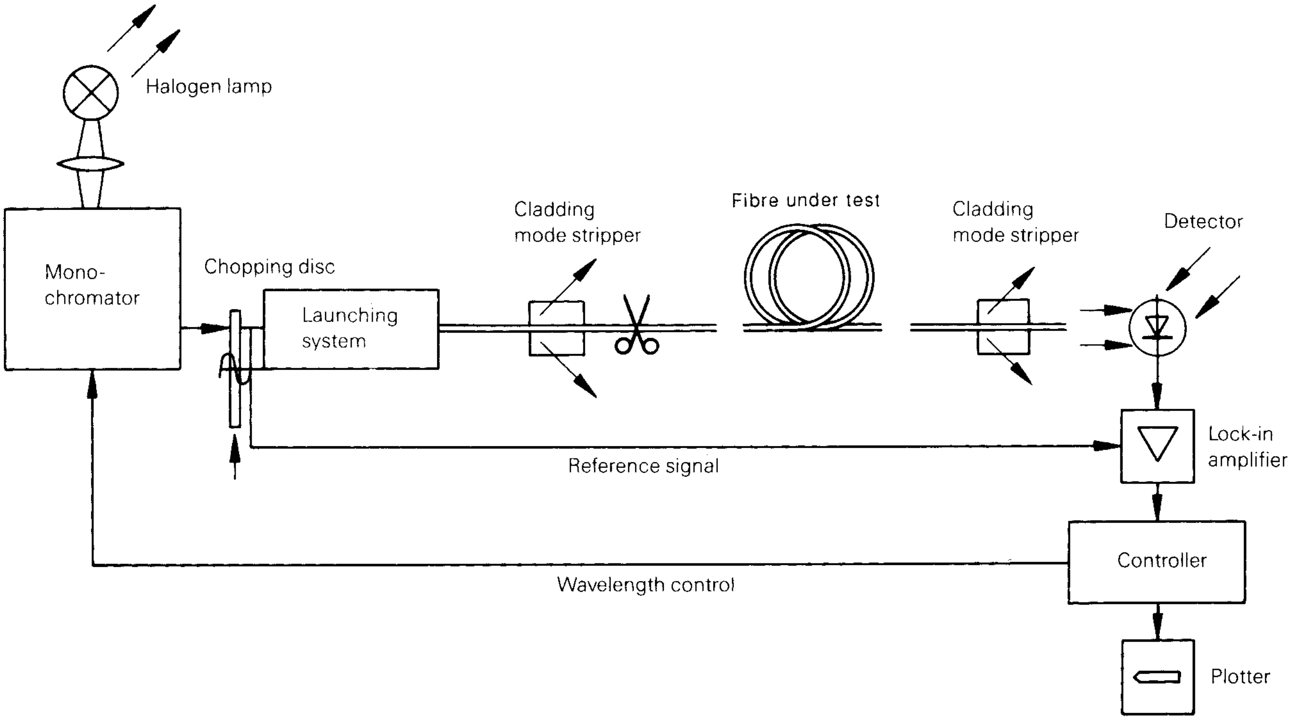

Figure A.2 – Arrangement of equipment used to obtain loss spectrum

A.1.1.1 General launch arrangement

Figure A.3 shows the general launch arrangement used for all fibres. See A.1.2 to A.1.4 for further details as they apply to specific categories of single-mode and multimode fibres.

A.1.1.2 Optical source

Use a suitable radiation source, such as a lamp, laser or light emitting diode. The choice of source depends upon the type of measurement. The source shall be stable in position, intensity and wavelength over a time period sufficiently long to complete the measurement procedure. Specify the spectral line width (between the 50 % optical intensity power points of the sources used) such that the line width is narrow, for example less than 10 nm, compared with any features of the fibre spectral attenuation. Align the fibre to the launch cone, or connect it coaxially to a launch fibre.

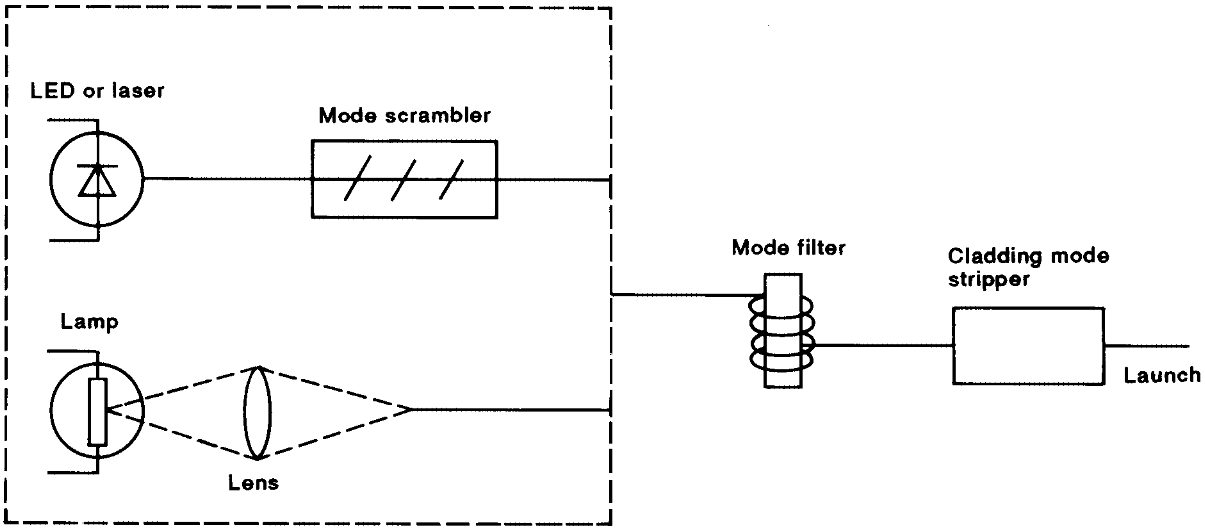

Figure A.3 – General launch arrangement

A.1.1.3 Source wavelength

Measurements may be made at one or more wavelengths. Alternatively, a spectral response may be required over a range of wavelengths.

A.1.1.4 Optical detection assembly

Means shall be provided to couple all power emitted from the specimen to the active region of the detector. For example, an optical lens system, a butt spliced to a fibre pigtail, or coupling directly to the detector may be used. If the detector is already pigtailed, the pigtail fibre shall have sufficiently large core diameter and numerical aperture to capture all of the light exiting the reference and specimen fibres.

Use an optical detector that is linear and stable over the range of intensities and measurement times that are encountered in performing this measurement. A typical system might include a photovoltaic mode photodiode amplified by a current input amplifier, with synchronous detection by a lock-in amplifier.

A.1.1.5 Signal processing

It is customary to modulate the light source in order to improve the signal/noise ratio at the receiver. If such a procedure is adopted, link the detector to a signal processing system synchronous with the source modulation frequency. The detecting system should be substantially linear or have known characteristics.

A.1.1.6 Cladding mode stripper

Use suitable techniques to remove optical power propagating in the cladding where this would significantly influence the received signal.

A.1.2 Launch apparatus for all single-mode fibres

An optical lens system or fibre pigtail may be employed to excite the test fibre. The power coupled into the fibre shall be stable for the duration of the measurement. See figure A.1.

A.1.2.1 Fibre pigtail

If using a pigtail, it may be necessary to use index-matching material between the source pigtail and test fibre to eliminate interference effects.

A.1.2.2 Optical lens system

If using an optical lens system, provide a means of stably supporting the input end of the fibre, such as a vacuum chuck. Mount this support on a positioning device so that the fibre end can be repeatedly positioned in the input beam. A method of making the positioning of the fibre less sensitive is to overfill the fibre end spatially and angularly.

A.1.2.3 High-order mode filter

Use a method to remove high-order propagating modes in the wavelength range of interest. An example of such a high-order mode filter is a single loop of radius sufficiently small to shift cut-off wavelength below the minimum wavelength of interest, but not so small as to induce wavelength-dependent oscillations.

A.1.2.4 Cladding mode stripper

The cladding mode stripper ensures that no radiation modes, propagating in the cladding region, will be detectable after a short distance along the fibre. The cladding mode stripper often consists of a material having a refractive index equal to or greater than that of the fibre cladding. This may be an index-matching fluid applied directly to the uncoated fibre near its ends; under some circumstances the fibre coating itself will perform this function.

A.1.3 Launch apparatus for A1 graded-index multimode fibres

The launching conditions are of paramount importance in meeting the objectives stated in clause 1. Launching conditions are established to avoid launching power into higher-order, transient modes. By not launching power into these transient modes of the test fibre, attenuations which add in an approximately linear fashion will be measured. Because these power distributions are essentially unaltered by the fibre, they are called "steady state distributions".

There are two commonly used techniques to produce steady-state launch conditions for attenuation measurements: mode filters and a geometrical optics launch. Proper care in the use of each technique gives comparable results. See figure A.1 for a generic example of the launching arrangement using a mode filter. Examples of each appear below.

A.1.3.1 Examples of mode filters

A.1.3.1.1 Dummy-fibre mode filter

Select a fibre of a similar type to that of the test fibre. The fibre should be long enough (typically equal to or greater than 1 km) so that the power distribution carried by the fibre, when the launch source of A.1.3.3 is used, is a steady-state distribution.

A.1.3.1.2 Mandrel-wrapped mode filter

Another mode filter takes the form of a mandrel around which a few turns (typically three to five turns) of the fibre under test are wound with low tension. Select the mandrel diameter to ensure that the transient modes excited in the test fibre have been attenuated to steady state. Use a far-field measurement to compare the power distribution exiting a long length of test fibre (greater than 1 km) that has been excited with a uniformly overfilling source, with the power distribution exiting a short length of the fibre with the mandrel applied. Select the mandrel diameter to produce a far-field distribution in the short length that approximates the long length far-field power distribution.

The numerical aperture (as measured by IEC 60793-1-43) of the radiation pattern exiting the short length shall be 94 % to 100 % of the numerical aperture of the long-length pattern.

The diameter of the mandrel may differ from fibre to fibre depending on fibre and coating type. Common prescriptions consist of diameters in the range of 15 mm to 40 mm, with five turns of fibre within a 20 mm length of the mandrel. While mandrels of different size and arrangement can be selected, the following table illustrates common mandrel sizes for fibres of different core diameters.

Table A.1– Mandrel sizes examples

Core diameter µm	**Mandrel diameter** µm
50	25
62,5	20
100	25

A.1.3.2 Example of geometrical optics launch

A limited phase space (LPS) launch is defined as a geometrically produced launch that uniformly fills 70 % of the test fibre's core diameter and 70 % of the test fibre's numerical aperture. This is the maximum geometrically launched power distribution that does not launch power into leaky, unbounded modes. For a 50/125 µm, 0,2 NA graded-index multimode fibre, the LPS launch condition consists of a uniform 35 µm spot and 0,14 NA.

An example of the optics necessary to produce the LPS launch is given in figure A.4. It is important to ensure that the axis of the launch beam is coincident with the axis of the fibre so that the spot and incident cone of light are centered on the core of the fibre. Also, set up the optical system at the wavelengths of operation to ensure proper measurement. While mandrels of different size and arrangement can be selected, common mandrel sizes for fibres of different core diameters, are shown in table A.1.

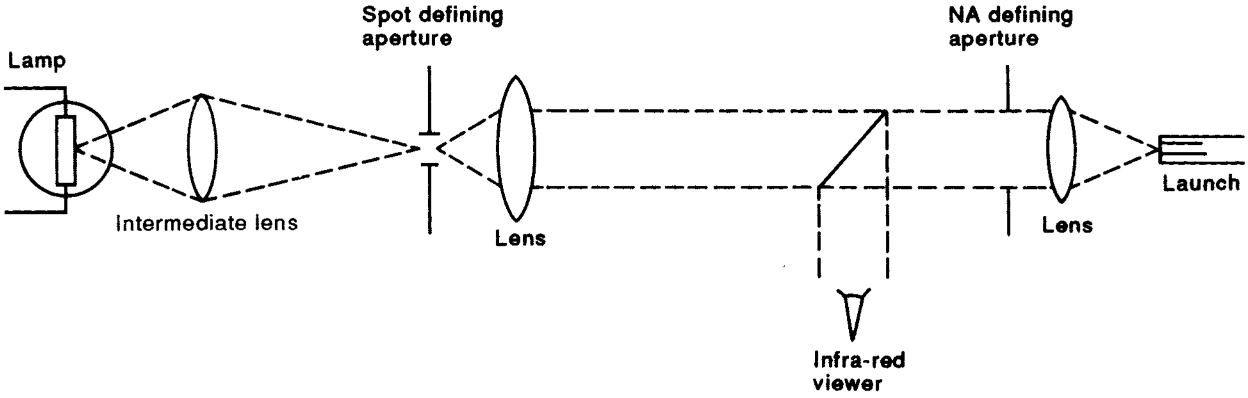

Figure A.4 – Limited phase space launch optics

A.1.3.3 Mode scrambler

An essentially uniform power distribution is launched prior to the mode filter. For a source such as a LED or laser which does not do so, use a mode scrambler. The mode scrambler shall comprise a suitable fibre arrangement (for example a step-graded-step index profile sequence).

A.1.4 Launch apparatus for A2 to A4 step-index multimode fibres

Some examples of generic launching arrangements for short-distance fibres are described in figures A.5, A.6 and A.7.

The reproducibility of the attenuation measurements of step-index fibres is critical. Therefore, a well defined launching set-up description is necessary. Such a set-up can be achieved by using commercially available optical components and shall be capable of providing for spot sizes and launch NAs as given in table A.2.

Table A.2 – Launch conditions for A2 to A4 fibres

Attribute	Fibre category		
	A2.2 (note 1) Glass core/glass cladding	**A3 Glass core/plastic cladding**	**A4 Plastic core/plastic cladding**
Spot size	= fibre core size	= fibre core size	= fibre core size with full mode launch (or use mode scrambler with equilibrium mode launch)
Numerical aperture	= fibre max NA (see note 2)	= fibre max NA (see note 3)	= fibre max NA, with full mode launch (see note 3)

NOTE 1 Category A2.1 fibre requires further study.

NOTE 2 This launch condition can be produced by overfilling a mode filter made from 2 m of fibre identical to the fibre under test, with appropriate cladding mode stripping and using the output from this mode filter to launch into the fibre under test.

NOTE 3 This launch condition can be produced in the same manner as described in note 2. However, some types of A3 and A4 fibre will not require cladding mode stripping for the mode filter.

A.1.5 Calibration requirements

Calibrate the wavelength to within ±10 nm.

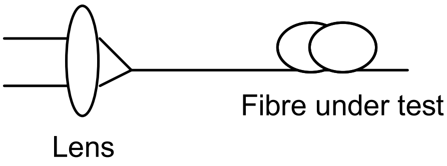

Figure A.5 – Lens system

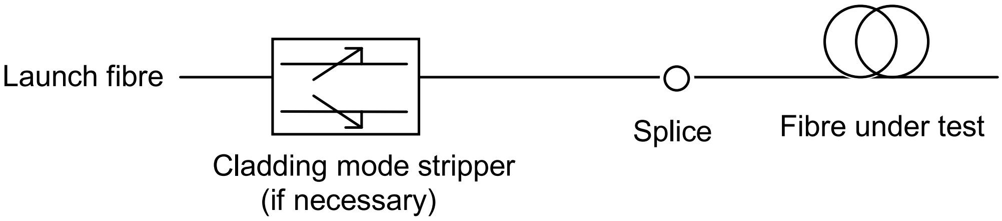

Figure A.6 – Launch fibre

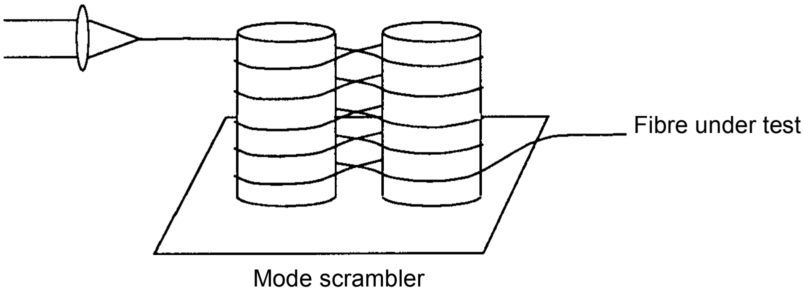

Figure A.7 – Mode scrambler (for A4 fibre)

A.2 Procedure

A.2.1 Set the fibre under test in the measurement apparatus. Record the output power, $P_2(\lambda)$.

A.2.2 Keeping the launching conditions fixed, cut the fibre to the cut-back length (for example, 2 m from the launching point). Record the output power, $P_1(\lambda)$, of the cut-back length.

A.3 Calculations

A.3.1 Calculate attenuation between the points where $P_1(\lambda)$ and $P_2(\lambda)$ have been measured, using equation (1) in 3.1, or attenuation coefficient by using equation (2) in 3.2, or both, as required.

A.3.2 Using attenuation measurement results at discrete wavelengths, a spectral attenuation curve can be calculated with relationships such as those described in annex D.

Annex B
(normative)

Requirements specific to method B – Insertion loss

The insertion loss technique is, in principle, similar to the cut-back technique, but $P_1(\lambda)$ is the power emerging from the output of the launching system.

The insertion loss technique is less accurate than the cut-back one, but has the advantage of being non-destructive for the fibre under test and for the terminators possibly fixed at both ends. Therefore it is suitable for field use, and mainly intended for use with connectorized cable lengths.

This method does not allow for analysis of the attenuation over the length of fibre. But by the previously known power, $P_1(\lambda)$, it is possible with this technique to measure the continuing change in attenuation over changing environmental conditions such as temperature and force.

B.1 Apparatus

B.1.1 General set-up

Figures B.1 (calibration) and B.2 (measurement) show diagrams of suitable measurement set-ups.

B.1.2 Apparatus common to (cut-back) method A

See the provisions of A.1.1. See also all of the appropriate information on launching conditions in A.1.2 (for single-mode fibre), A.1.3 (for A1 graded-index multimode fibre), and A.1.4 (for A2 to A4 step-index multimode fibre).

B.1.3 Additional apparatus specific to (insertion-loss) method B

The insertion-loss technique requires the use of a very precise fibre-to-fibre coupling device in order to minimize the coupling losses and to ensure reliable results. This coupling device can be a mechanical adjustment that is visually inspected, or a connector with a core-to-core positioning.

B.2 Procedure

B.2.1 The reference fibre shall be of the same type as that under test. Any connectors and their associated losses are included in the definition of the reference fibre.

B.2.2 Initially calibrate the measurement equipment in order to obtain an input reference level, $P_1(\lambda)$. Use the same fibre type as a reference fibre at the initial calibration. The length of the reference fibre should be small (for example, 2 m) so that its attenuation can be neglected. (If the attenuation of the reference fibre cannot be neglected, add the value to the calculated value.)

B.2.3 Connect the fibre under test to the measurement apparatus and adjust the coupling to give a maximum level on the optical detector. Record the output power, $P_2(\lambda)$.

B.3 Calculations

Calculate attenuation by using equation (1) in 3.1, or the attenuation coefficient by using equation (2) in 3.2, or both, as required.

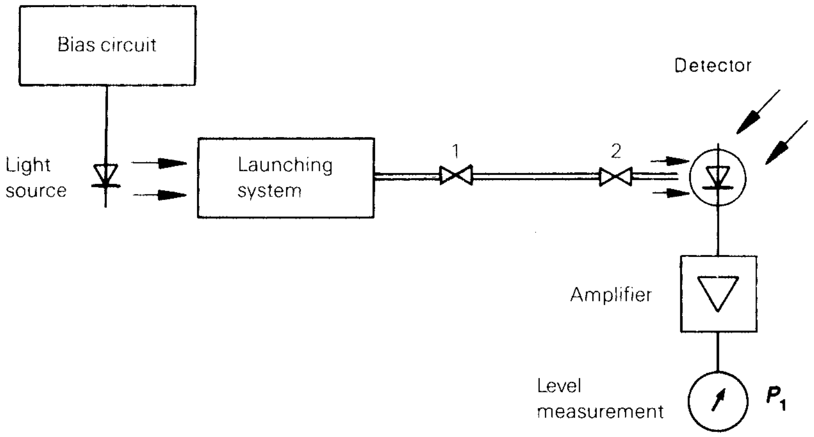

Figure B.1 – Calibration of insertion loss measurement set

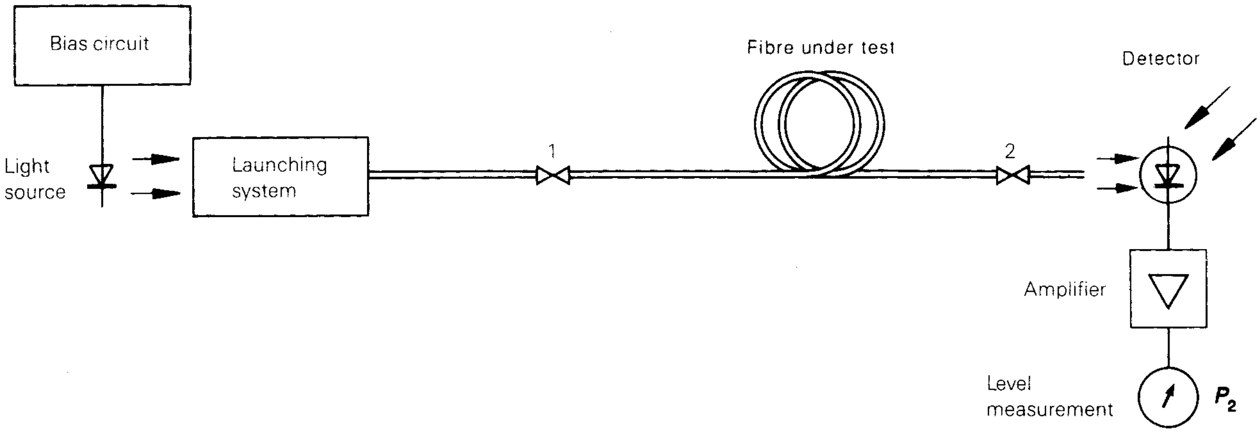

Figure B.2 – Measurement of insertion loss

Annex C
(normative)

Requirements specific to method C – Backscattering

The backscattering method, which is a single-sided measurement, measures the optical power backscattered from different points in the fibre to the beginning of the fibre.

The measurement is affected by the propagation speed and the backscattering behaviour of the fibre and may not be accurate for measuring fibre attenuation. The technique can only be used to measure the fibre's attenuation by taking the backscatter measurements from both ends of the fibre under test and averaging the two backscatter traces.

This technique allows analysis of the entire fibre, particularly of longitudinal subsections of the fibre, or even identification of discrete points such as splices. It also permits calculation of the fibre length.

Methods to describe the uniformity of attenuation from the bi-directionally averaged backscattered traces are under consideration. It is expected that they will appear as an IEC technical specification.

C.1 Apparatus

This method uses an optical time-domain reflectometer (OTDR), which shall normally consist of the following minimum list of components. See figure C.1 for a block diagram.

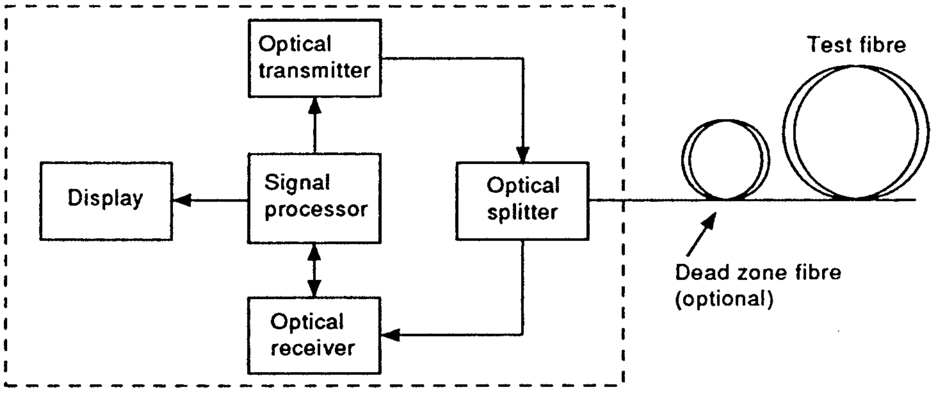

Figure C.1 – Block diagram of an OTDR

C.1.1 Optical transmitter

This usually includes one or more pulsed laser diode sources capable of one or more pulse durations and pulse repetition rates. Unless otherwise specified in the detail specification, the spectrum for each wavelength shall satisfy the following.

C.1.1.1 The central wavelength shall lie within 15 nm of the specified value; report the difference between the central wavelength and the specified value if it is greater than 10 nm.

C.1.1.2 The root-mean-squared width (RMSW) shall not exceed 10 nm, or the full width at half maximum (FWHM) shall not exceed 25 nm.

C.1.1.3 If the data are to be used in a spectral attenuation model:

- the spectral width shall not exceed 15 nm (FWHM) or 6 nm (RMS) for wavelengths in the water peak absorption region (e.g., 1 360 nm to 1 430 nm);
- report the actual central wavelength to within 2 nm of the actual value.

C.1.2 Launch conditions

Provide a means for connecting the test fibre (or the optional dead-zone fibre of C.1.9) to the instrument panel, or to a fibre pigtail from the source.

For type A fibre, optical sources may not produce launch conditions that are well controlled or appropriate to this measurement method. Therefore, unless otherwise specified in the detail specification, launch conditions for attenuation measurements shall be those used in cut-back attenuation measurements (method A).

C.1.3 Optical splitter

A coupler/splitter within the instrument directs the power from the transmitter into the fibre. It also directs light returning in the fibre from the opposite direction to the receiver.

C.1.4 Optical receiver

This usually includes a photodiode detector having a bandwidth, sensitivity, linearity, and dynamic range compatible with the pulse durations used and signal levels received.

C.1.5 Pulse duration and repetition rate

The OTDR may be provided a choice of several pulse durations and repetition rates (sometimes coupled to the distance control) to optimize the trade-off between resolution and range. With a high amplitude reflection, it may be necessary to set the rate or range to a value exceeding twice the distance of the reflection in order to prevent spurious ‘ghost’ images. Pulse coding techniques may also be used.

NOTE Care should be taken when selecting the pulse duration, repetition rate, and source power. For shorter distance measurements, short pulse durations are necessary in order to provide adequate resolution. This in turn will limit dynamic range and maximum measurable length. For long length measurements, the dynamic range can be increased by increasing the peak optical power up to a level below which non-linear effects are insignificant. Alternatively, pulse width can be increased, which will reduce the resolution of the measurements.

C.1.6 Signal processor

If required, the signal-to-noise level may be increased by the use of signal averaging over a longer measurement time.

C.1.7 Display

This is incorporated into the OTDR and is part of the equipment controlling the OTDR. The OTDR signal is displayed in a graphical form with the vertical scale as decibels and the horizontal scale as distance. The vertical decibel scale shall correspond to half the round-trip of the backscatter loss. The horizontal scale shall correspond to half the associated optical group delay, converted to distance. Tools such as cursors may be used to manually or automatically measure all or part of the OTDR trace on the display.

C.1.8 Data interface (optional)

The instrument may be capable of interfacing with a computer for automatic analysis of the signal or for providing a hard copy of the display trace.

C.1.9 Reflection controller (optional)

Means of minimizing transient saturation of the receiver due to high Fresnel reflections may be required to reduce the length of fibre "dead zone" following each reflector. This can be incorporated into the coupler/splitter, or may be done by electronic masking. To overcome the initial reflection at the OTDR connector, a dead-zone fibre (with a length in metres numerically exceeding one-tenth the displayed pulse duration in nanoseconds) may be used between the OTDR connector and the specimen.

C.1.10 Splices and connectors

Unless otherwise indicated in this procedure, any splices or connectors required by the OTDR (e.g., to join the OTDR or the dead-zone fibre to the test fibre) shall have low insertion loss and reflectance (high return loss). This is to minimize extraneous effects upon the OTDR trace of interest.

C.2 Sampling and specimens

This is a fibre on a reel or within a cable, under conditions specified in the detail specification. The measurement may be performed in the factory or in the field, upon either single or concatenated sections.

NOTE Care should be taken to ensure that winding does not introduce artificial attenuation for point discontinuity or attenuation measurements. Alternatively, any induced loss confined to the ends of the fibre length (as with the first layer on a reel) can be excluded in a calculation of the attenuation coefficient.

C.3 Procedure

The use of an OTDR for indirect measurement of attenuation or fibre attenuation coefficient of an optical fibre or fibre cable is described below.

For type A1 and A2 optical fibres, more accurate values may be obtained by using spectral attenuation cut-back measurements. If the values obtained by these two techniques differ from each other, the values from the cut-back technique will be accepted as correct, unless otherwise specified in the detail specification.

For type B1 and B2 optical fibres, by performing these measurements at multiple wavelengths, a spectral attenuation curve can be generated using relationships such as those described in method D (see annex D).

C.3.1 Connect the specimen either to the instrument or to one end of the dead-zone fibre (if used). Connect the other end of the dead-zone fibre (if used) to the instrument.

C.3.2 If the attenuation coefficient and accurate distances are to be recorded, the effective group-delay index of the specimen is required. If this value is not known, use the procedure for the OTDR measurement of fibre or cable length (method B of IEC 60793-1-22) to determine it.

C.3.3 Enter OTDR parameters such as source wavelength, pulse duration, length range, and signal averaging into the instrument, along with the specimen's effective group-delay index (if required by C.3.2). The values of some of these parameters may be preset in the instrument.

C.3.4 Adjust the instrument to display a backscatter signal from the specimen. It may be advantageous to begin with coarse vertical and horizontal scaling to maximize the length displayed. Figures C.2 and C.3 give examples for use with measuring attenuation and figures C.4 and C.5 are example schematics for use with measuring point discontinuities.

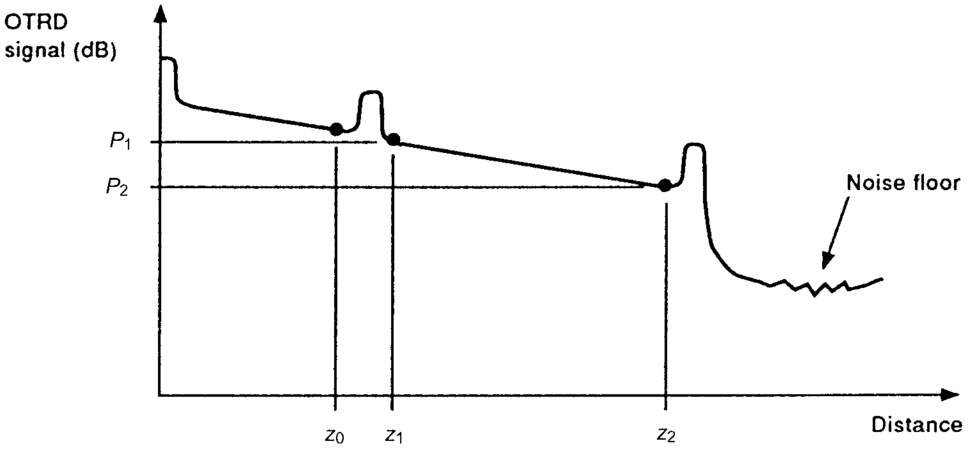

Figure C.2 – Schematic OTDR trace for a "uniform" specimen preceded by a dead-zone fibre

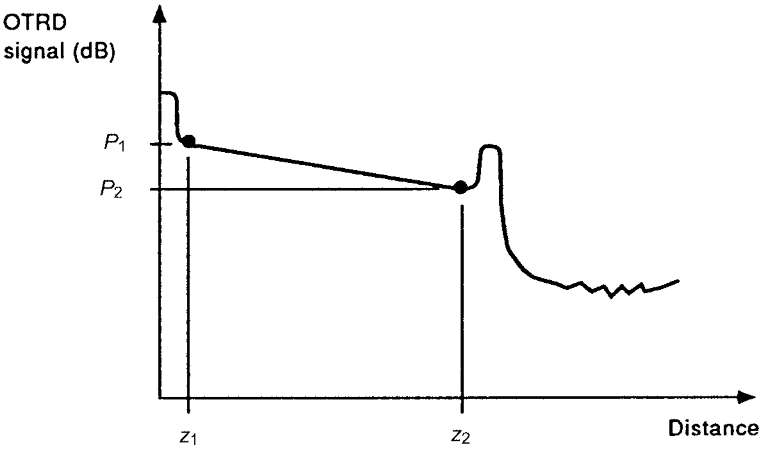

Figure C.3 – Schematic OTDR trace for a "uniform" specimen not preceded by a dead-zone fibre

C.3.5 Further steps for measuring attenuation

C.3.5.1 Step 1

If increased resolution is needed, adjust the graphical display, if possible, to expand the section of interest to a larger scale (exercising care to ensure that proper readings of the true signal can still be distinguished from the noise points).

C.3.5.1.1 (Also optional with C.4.3) If using a dead-zone fibre, refer to figure C.2. Place a cursor at the beginning of the specimen prior to any power drop-off (which may be difficult to do), or at a point (which may be specified by the manufacturer) on the rising edge of the reflection pulse. (If the beginning is not apparent due to a minimal discontinuity, apply a tight bend at this location and vary the radius to assist in cursor placement.) Obtain the distance coordinate, z_0, via the alphanumeric display. If a dead-zone fibre is not used, no cursor placement is required; take $z_0 = 0$.

C.3.5.1.2 Place a cursor on the beginning of the linear portion (after the near end) of the trace for the specimen. If using the dead-zone fibre (figure C.2), place the cursor beyond the recovery from the small reflection at the end of the dead-zone fibre. If not using the dead-zone fibre (figure C.3), place the cursor beyond the dead-zone of the OTDR connector. Obtain the distance and power coordinates, $[z_1, P_1(\lambda)]$, via the alphanumeric display.

C.3.5.1.3 Place the same or another cursor at the end of the specimen at a point similar to that in C.3.5.1.1. If the end is not apparent due to minimal discontinuity, apply a tight bend at this location and vary the radius to assist in cursor placement. Alternatively, cleave the fibre far end, if possible, to produce a reflection there. Obtain the coordinates, $[z_2, P_2(\lambda)]$.

C.3.5.1.4 Repeat the relevant tests of C.3 at each wavelength required.

C.3.5.2 Step 2

Repeat the measurement for a signal launched into the specimen in the opposite direction. To obtain accurate attenuation values, bi-directional traces at the same wavelength are averaged, so as to eliminate the effects of length varying backscatter properties.

C.3.6 Further steps for measuring point discontinuities

C.3.6.1 Examine the OTDR signal along the specimen for point discontinuities as defined in 3.4. If increased resolution is needed, adjust the graphical display, if possible, to expand the section of interest to a larger scale (exercising care to ensure that proper readings of the true signal can still be distinguished from the noise points). See figure C.5 for an example.

C.3.6.2 To determine that a point discontinuity (rather than an attenuation non-uniformity situation) exists, observe the area in question, using two different pulse durations. If the shape of the loss or gain changes with the pulse duration, the anomaly is a point discontinuity. If the shape does not change, consider the anomaly to be an attenuation non-uniformity to be measured according to the test procedure for measurement of fibre or cable attenuation. Alternatively, if the OTDR pulse shape and duration are known, the resultant shape of the backscatter curve at point discontinuities may be used to determine their existence.

C.3.6.3 Report any point discontinuity deviations that exceed the values specified in the detail specification. Describe the nature of these discontinuities (e.g. apparent loss or gain, reflection, duration, etc.), as required by the detail specification.

C.3.6.3.1 Determine the discontinuity location, if required, by placing a cursor at the beginning (or at another point specified by the OTDR manufacturer) of a power rise or drop. This may be difficult to do for a power drop. Obtain the coordinate via the alphanumeric display.

C.3.6.3.2 Obtain the apparent loss or gain of the discontinuity, if required, by the method described by the OTDR manufacturer. Some instruments require placement of a pair of cursors on each side of the discontinuity. Extrapolate the two best-fit straight lines (from a two-point or least-squares fit for each) to the location of the discontinuity. If available, the linear fit method should be chosen. The vertical separation of the lines gives the apparent loss or gain.

Note any reflection peak. The height of a given peak will decrease with increasing pulse width and increase with decreasing pulse width.

C.3.6.3.3 Repeat the test for a signal launched into the specimen in the opposite direction. Make a loss calculation (and the elimination of apparent gain) by averaging readings taken bi-directional at the same wavelength. This eliminates the effects of any backscatter differences for the fibre sections on both sides of the discontinuity. Bi-directional measurements may not be possible in all cases, thus necessitating unidirectional measurement.

C.3.6.3.4 If required by the detail specification, repeat the test at another wavelength.

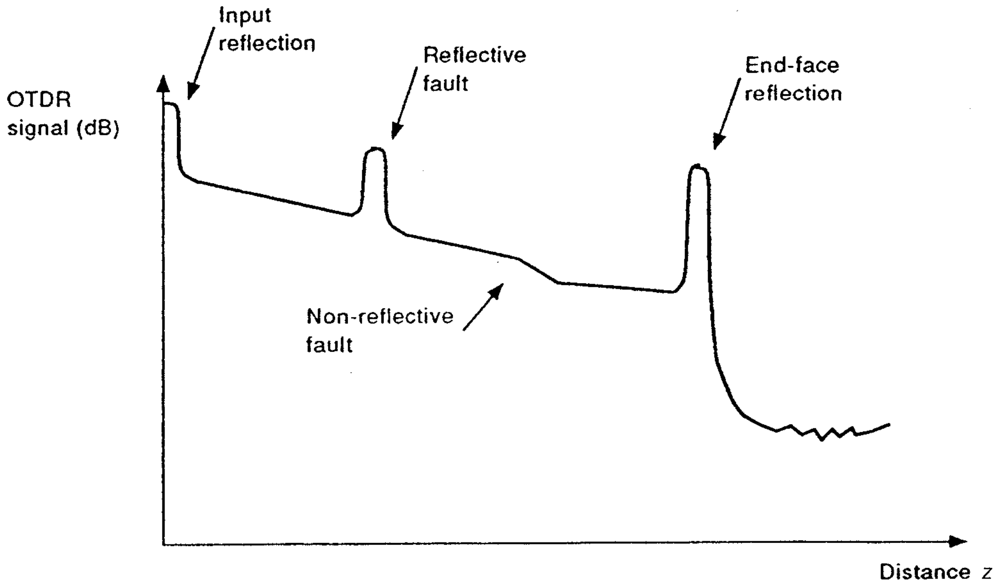

Figure C.4 – Schematic OTDR trace showing apparent loss due to point discontinuities, one reflective and one non-reflective

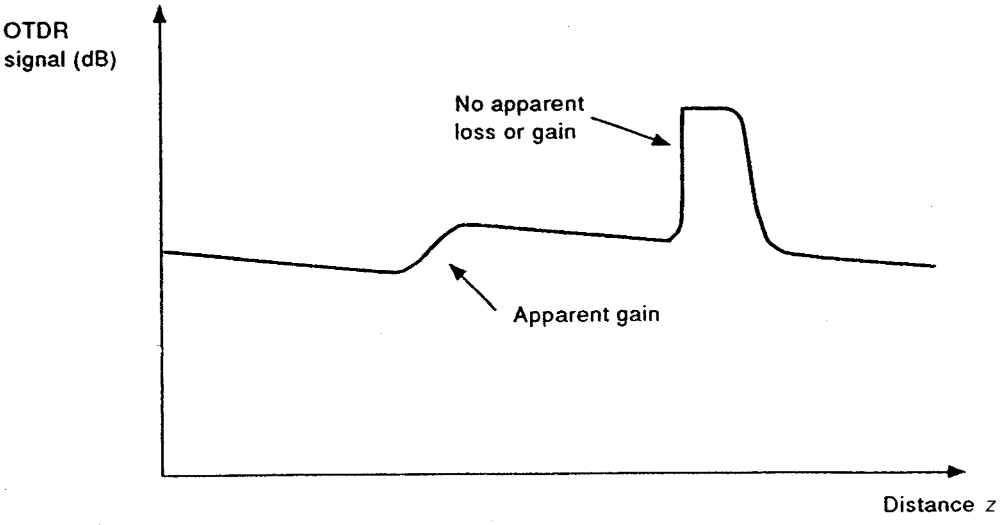

Figure C.5 – Schematic of an expanded OTDR trace showing two point discontinuities, one with apparent gain, and another with no apparent loss or gain

C.3.7 Calibration

Under consideration.

C.4 Calculations

C.4.1 The unidirectional backscatter attenuation of the fibre or cable section beginning after the dead zone is given by $[P_1(\lambda) - P_2(\lambda)]$ in dB.

C.4.2 The unidirectional backscatter attenuation coefficient of the fibre or cable section is given by $\alpha = [P_1(\lambda) - P_2(\lambda)]/(z_2 - z_1)$ in dB/km.

C.4.3 (Optional with C.3.5.1.1) The unidirectional backscatter attenuation of the total fibre or cable section is given by $[P_1(\lambda) - P_2(\lambda)] + \alpha (z_1 - z_0)$ in dB (where λ is given in C.4.2), or equivalently by $[P_1(\lambda) - P_2(\lambda)](z_2 - z_0)/(z_2 - z_1)$, in dB.

C.4.4 Some OTDRs can automatically perform the two-point subtractions in C.4.1 to C.4.2.

NOTE Some OTDRs can also utilize a least-squares fit to a line, but this may give results that differ from the two-point subtractions. The type of calculation is indicated in the detail specification. The least-square average (LSA) may be the more repeatable due to noise effects, but can err in the presence of inhomogeneities.

C.4.5 As for C.3.6, repeat the calculations for the measurements made at each wavelength in the opposite direction. Compute the average of the two calculations made in C.4.2 to arrive at the fibre's attenuation coefficient at that wavelength.

C.4.6 Repeat the calculations of C.4.1 through C.4.5 at each wavelength so as to determine the attenuation coefficient at each wavelength.

C.5 Results

C.5.1 In addition to the requirements of 7.1, report the following when measuring point defects:

- specimen end where the OTDR was located;
- features of the point discontinuities as required by the detail specification.

C.5.2 In addition to the requirements in 7.2, the following information shall also be available on request:

- fibre or cable specimen, including its type, effective group index, length, and deployment conditions;
- OTDR instrument (including mark, model and manuals);
- pulse duration(s), scale range(s), and signal averaging details;
- central wavelength(s) and spectral width(s) as periodically verified in C.1.1;
- indicate if dead-zone fibre is used;
- method of calculation.

The figures show examples of OTDR traces for several types of point discontinuities: a reflective discontinuity and a non-reflective one, both exhibiting apparent loss (figure C.4); a discontinuity exhibiting an apparent "gain", and one with no apparent loss or gain (figure C.5).

Annex D
(normative)

Requirements specific to method D –

Spectral attenuation modelling

To date, method D has only been demonstrated on type B1 and B2 fibres.

The attenuation coefficient of a fibre across a spectrum of wavelengths may be calculated by means of a characterizing matrix, M, and a vector, v. The vector v contains the measured attenuation coefficients of a small number (three to five) of wavelengths (e.g. 1 310 nm, 1 330 nm, 1 360 nm, 1 380 nm, and/or 1 550 nm).

In one approach, the fibre or cable supplier shall provide a matrix characteristic of its product, and the modelled spectral attenuation is a vector, w, calculated from the product of M and v:

$$w = M \times v \tag{D.1}$$

Alternatively, if using a generic matrix, the supplier shall provide a correction factor vector e, such that the prediction equation becomes

$$W = w + e \tag{D.2}$$

where

W is the modified vector;

w comes from equation (D.1);

e is the correction factor vector.

A generic matrix is a characterizing matrix which can be applied to a variety of fibres, designs and suppliers (presumably within a single fibre type), and which is determined and/or invoked by a standards body, single customer/end-user, or other industry source to which individual suppliers can compare their products, the difference being resolved by the vector, e.

D.1 Apparatus

Since this technique involves a calculation using predetermined values, there is no specific apparatus required. Please refer to the specific technique used to generate the measured values upon which the calculations are made.

D.2 Sampling and specimens

See D.1.

D.3 Procedure

See D.1.

D.4 Calculations

The attenuation coefficient of a fibre across a spectrum of wavelengths may be calculated by means of equation (D.1). The vector, *v*, contains the measured attenuation coefficients of a small number (three to five) of predictor wavelengths (e.g., 1 310 nm, 1 330 nm, 1 360 nm, 1 380 nm, and/or 1 550 nm). Multiplying the matrix, *M*, times the vector, *v*, yields another vector, *w*, which contains the predicted attenuation coefficients at many wavelengths (such as at 10 nm wavelength intervals from 1 240 nm to 1 600 nm). The resultant vector, w, contains the predicted attenuation coefficients at many wavelengths (such as a 10 nm wavelength intervals from 1 240 nm to 1 600 nm).

The matrix, *M*, is given by:

$$\begin{array}{lll} A_{11} & A_{12}\cdots\cdots\cdots & A_{1n} \\ A_{21} & A_{22}\cdots\cdots\cdots & A_{2n} \\ '' & '' & \\ '' & '' & \\ '' & '' & \\ A_{m1} & A_{m2}\cdots\cdots\cdots & A_{mn} \end{array}$$

where

m is the number of wavelengths for which the attenuation coefficients have to be estimated;

n is the number of predictor wavelengths.

The standard deviation of the difference between the actual and predicted attenuation coefficients at each wavelength shall be less than 0,xx dB/km within a stated wavelength range. A different tolerance – 0,yy dB/km – may be necessary if an additional wavelength range is specified. The values of xx (and yy), and the wavelength range(s) should be agreed upon between the user and the manufacturer.

If the estimate is obtained by using the supplier's specific matrix, *M*, then no correction vector, *e*, is necessary.

Since the elements of both *M* and *e* are achieved on a statistical basis, the *w* vector elements shall be determined as statistical. To indicate the accuracy of the predicted attenuation coefficients, the fibre suppliers shall give a vector containing the standard deviation of the differences between the actual and predicted attenuation coefficients, together with *M* and/or *e* (see D.5).

NOTE 1 In order to facilitate the use of this matrix, the fibre should be routinely measured at the predictor wavelengths. The predictor wavelengths should number from three to five, with a strong preference given to the lower number if sufficient accuracy can be achieved. The specific wavelengths (e.g., 1 310 nm, 1 330 nm, 1 360 nm, 1 380 nm, and/or 1 550 nm) are an item for further study.

NOTE 2 This model considers only uncabled fibre attenuation. An additional vector should be added to *w* in order to account for cabling and environmental affects.

D.5 Results

D.5.1 In addition to the information required by 7.1, report the predicted attenuation and corresponding wavelength.

D.5.2 In addition to the information required by 7.2, the following shall be available upon request:

- the method used to obtain the measured attenuation values;
- the matrix used to predict the spectral attenuation, or the correction vector if a standard matrix was used;
- the vector containing the standard deviation of the differences between the actual and predicted attenuation coefficients obtained during the development of the matrix.

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